Cold Water Refugia Workshop Presentation

Background and Summary of Scientific Studies on how elevated temperatures effect adult Salmon and Steelhead use of cold water refugia and survival in the Columbia River

EPA Columbia River Cold Water Refugia Project
June 1, 2016 Workshop

Columbia & Willamette Rivers Cold Water Refugia Plans

- EPA to develop a Columbia River CWR Plan
- Goal: Characterize and evaluate the sufficiency of CWR habitats for salmon and steelhead migrating through the Columbia River
- Oregon DEQ to develop a Willamette River CWR Plan
- Complete by November 2018
- Completing these plans is part of NOAA 2015 BiOp Reasonable and Prudent Alternative

Background

- NOAA 2015 Jeopardy Biological Opinion on EPA's Approval of Oregon's Temperature Water Quality Standards

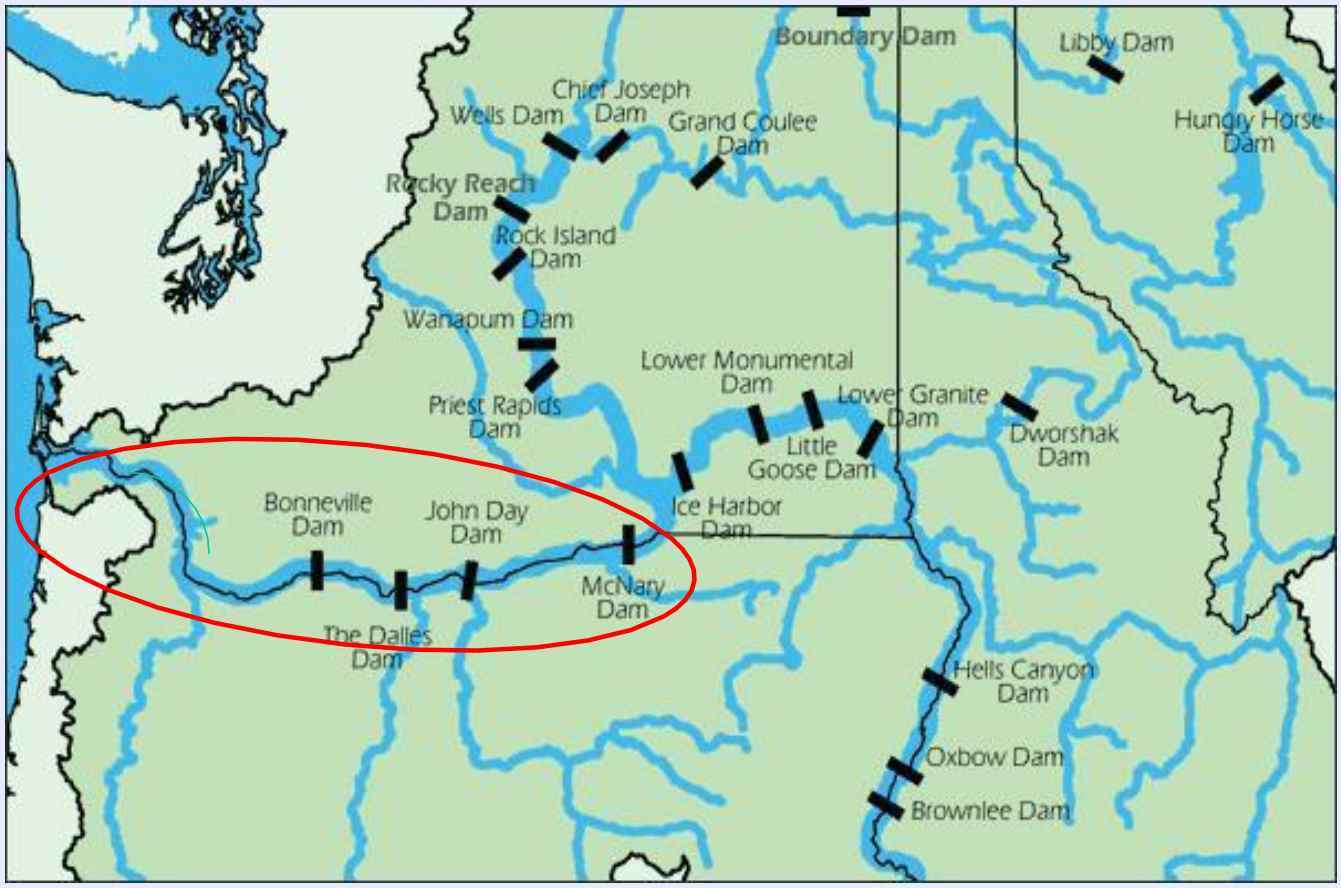
- Oregon Columbia/Lower Willamette River Temperature Criteria
  - 20C numeric criteria, plus
  - Cold Water Refugia (CWR) narrative criteria
    - "must have CWR that's sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher temperatures elsewhere in the water body"
    - "CWR means those portions of a water body where, or times during the diel cycle when, the water temperature is at least 2C colder than the daily maximum temperature of the adjacent well mixed flow of the water body"

- NMFS concluded CWR narrative criteria is not an effective criteria due to lack of implementation
  - Jeopardy for Steelhead (LCR, UWR, MCR, UCR, SRB); Chinook (LCR, UWR); Sockeye (SR); SR Killer Whales

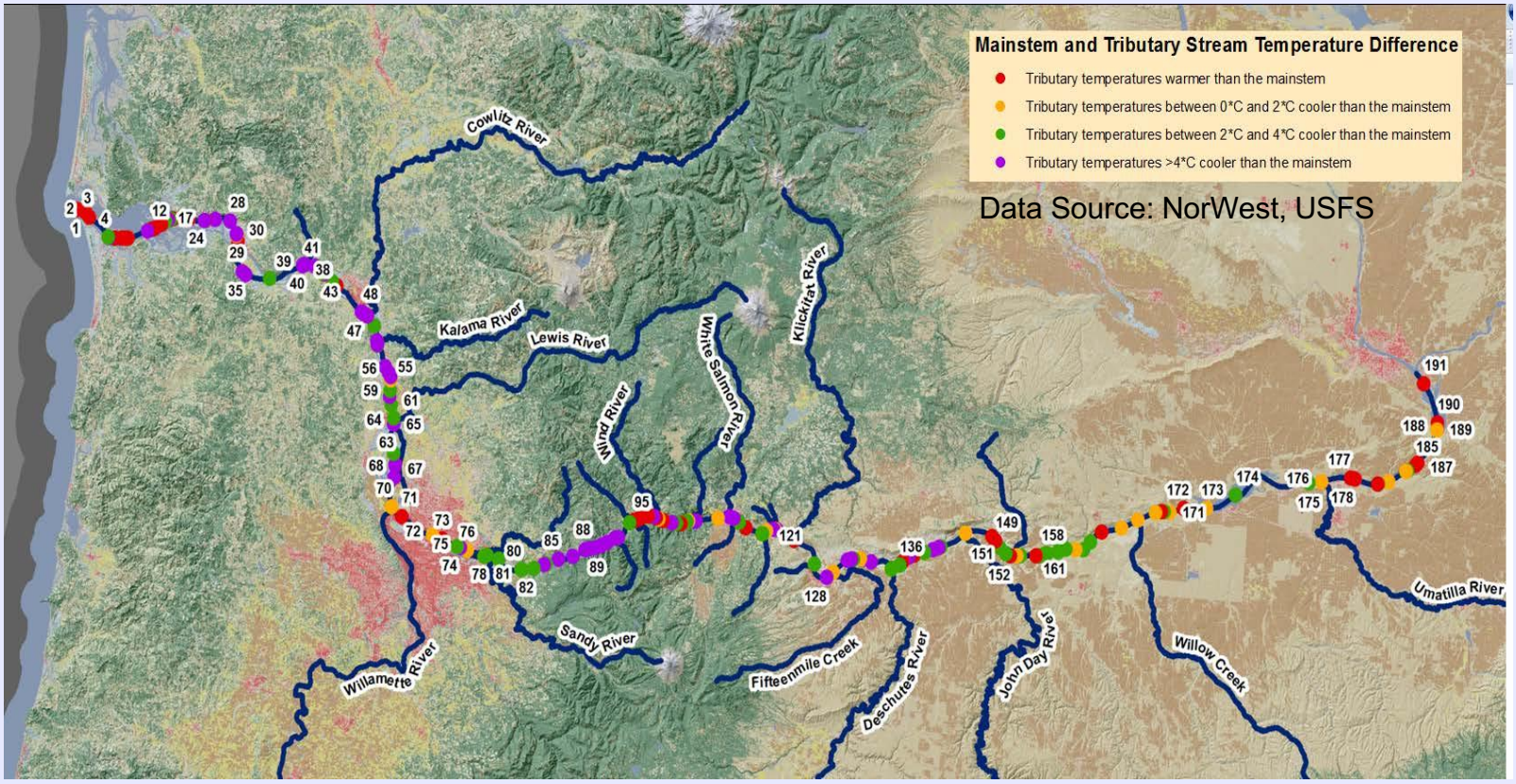
Cold Water Refugia (CWR) Plan Elements

1. Characterize current spatial and temporal CWR
2. Characterize current salmon and steelhead use of CWR
3. Assess whether current CWR is sufficient to meet Oregon's narrative criteria
4. Identify potential locations to restore CWR
5. Identify additional CWR needed to meet criteria
6. Identify and prioritize actions to protect, restore, or enhance CWR

Columbia River CWR Plan Area RM0-RM310



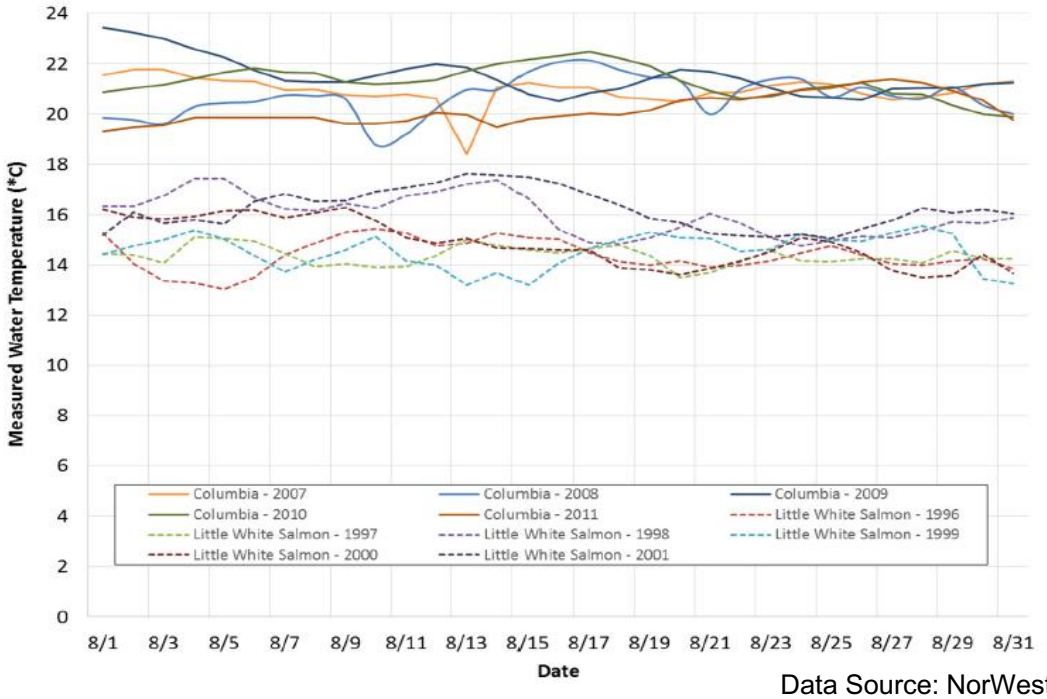
Columbia River CWR Tributaries



Little White Salmon vs Columbia River Temperatures

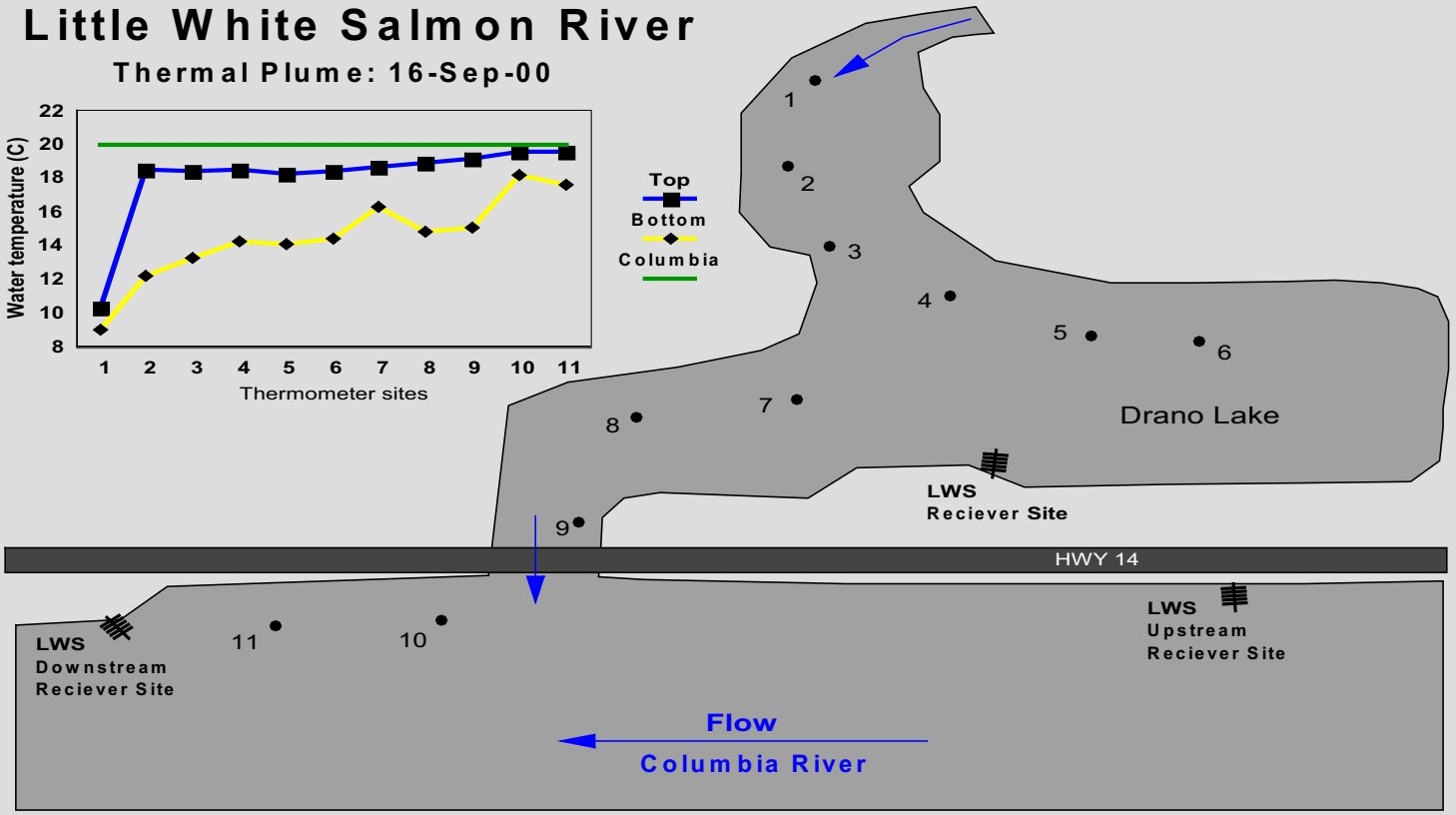
Tributary #112 – Little White Salmon River

Daily Average Water Temperature



Data Source: NorWest, USFS

Little White Salmon CWR Plume (Data source: U of I)



Focus of Today's Workgroup

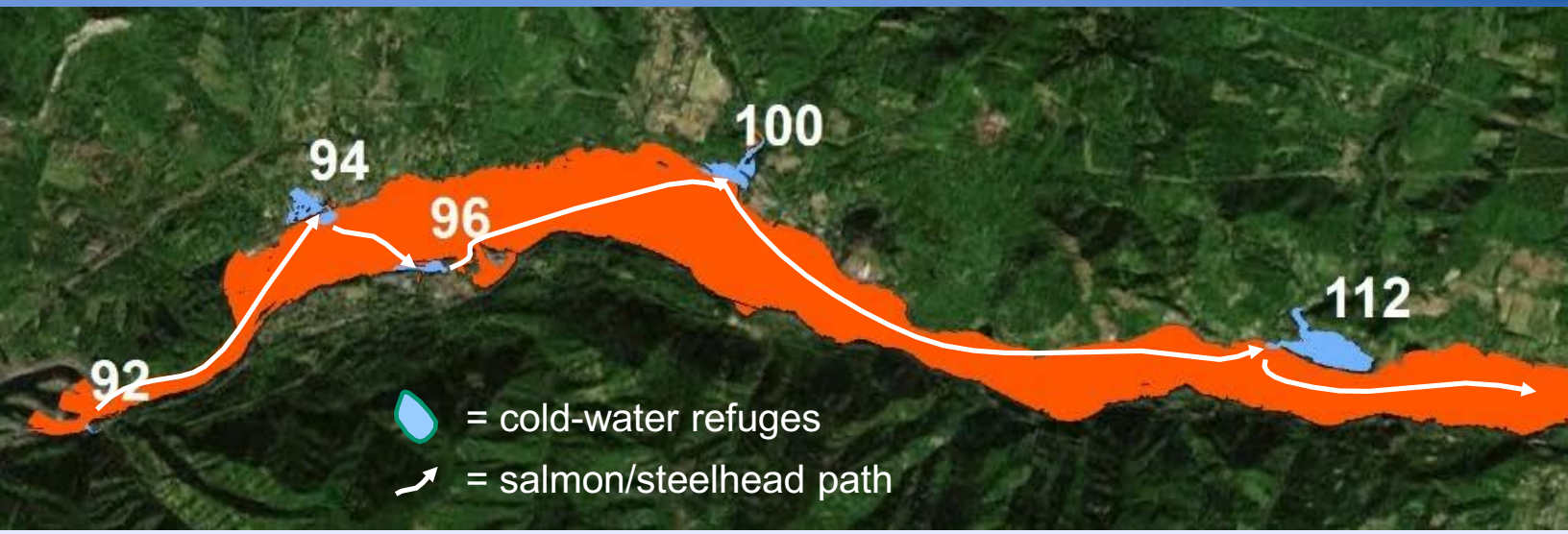
- Element #2 - Characterize current salmon and steelhead use of CWR
  - EPA has conducted literature review summarized in ppt
  - Seeking input both today and in subsequent follow-up
  - Set of discussion questions for group discussion
    - EPA recognizes we can't fully address all questions today
  - EPA will then draft Chapter 2 of the Columbia River CWR Plan

- Today will also help set the foundation for Element #3 - Assess whether current CWR is sufficient to meet Oregon's narrative criteria

Assessing Sufficiency

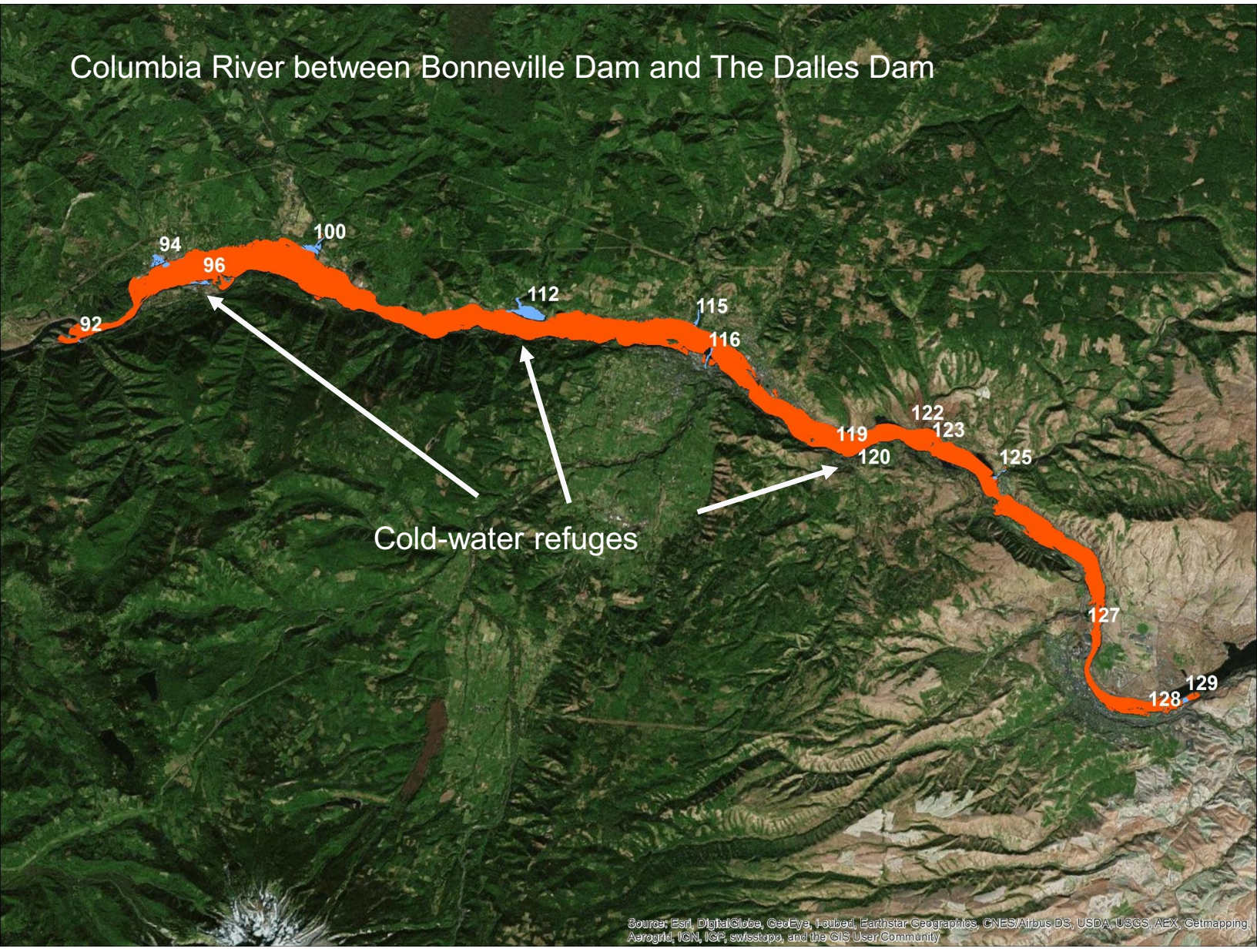
- Characterize the thermal environment encountered by migrating salmon and steelhead
- Identify trade-offs of thermal refuge use by migrating adult salmon and steelhead
- Evaluate net effects for salmon and steelhead migration survival and reproductive success

HexSim Model Overview



- Track individuals over time
  - Accumulated thermal exposure as fish migrate
  - Differential exposure to other risks (harvest, predation, disease)
  - Net effect on survival, egg viability
- Allows comparison of travel paths, spacing, size, quality of cold-water refuges

How does the availability and use of cold-water matter to salmon and steelhead?


Columbia River between Bonneville Dam and The Dalles Dam
92
94
96
100
112
115
116
119
120
122
123
125
127
128
129
Cold-water refuges
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Number of Adult Salmon/Steelhead Passing Bonneville Dam in Summer

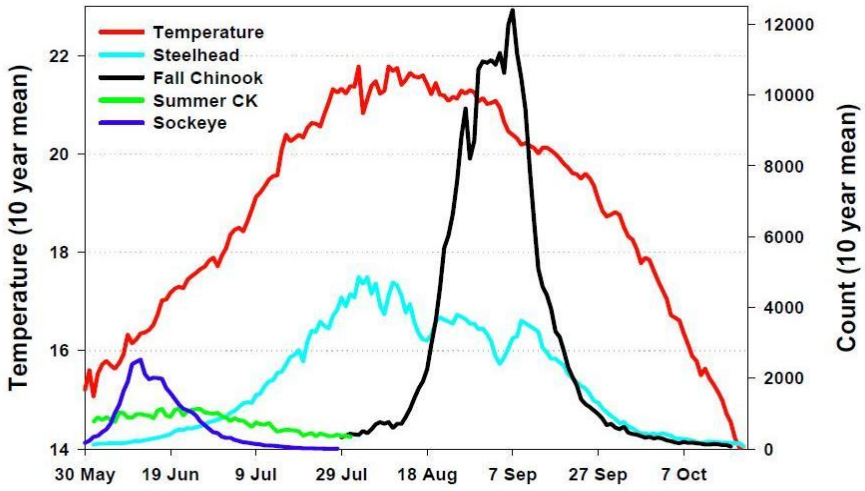


Figure 2. Ten-year (1996-2005) mean lower Columbia River water temperature (°C) and mean run size and timing of adult summer Chinook salmon, fall Chinook salmon, sockeye salmon, and summer steelhead at Bonneville Dam. Thermal refugia use by many adult populations has been associated with water temperatures greater than 19-20 °C.

Source: Keefer et. al. 2011

	Number of Fish per Day					
	July 1-10	July 11-21	July 22-31	Aug 1 -10	Aug 11- 21	Aug 22- 31
Summer Chinook	1,600	1,000	500	0	0	0
Sockeye	5,000	2,000	100	0	0	0
Steelhead	1,000	3,000	5,000	5,000	4,000	4,000
Fall Chinook	0	0	0	100	2,000	10,000
Total	7,600	6,000	5,600	5,100	6,000	14,000

Source: Fish Passage Center 2014 Annual Report – Rough Est. from Graphs

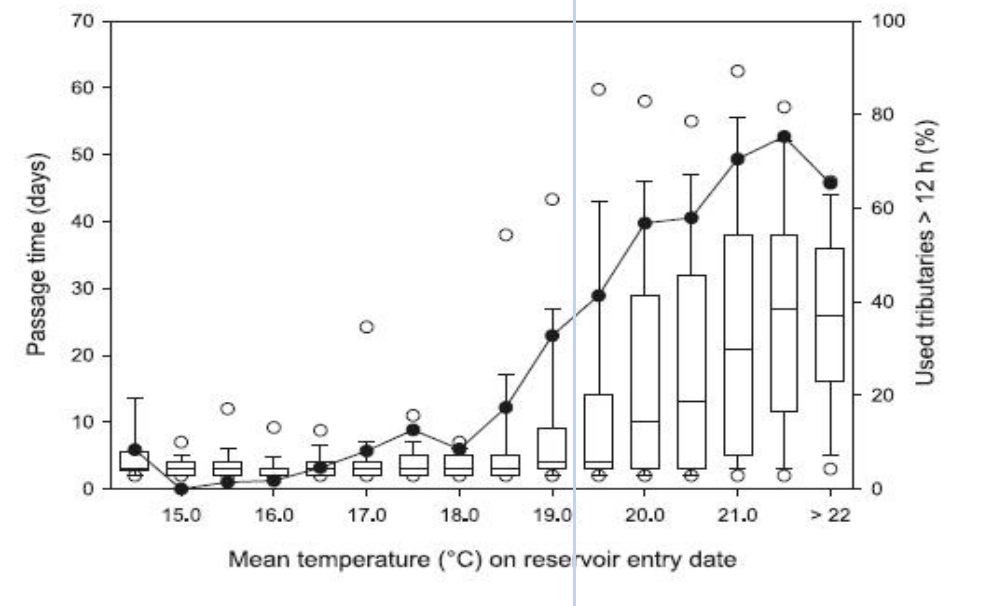
Summer Steelhead - Overview

- Most Steelhead pass Bonneville Dam from July 1 – Sept 30
  - 90% pass over 3 month period
- 350,000 adult steelhead pass Bonneville Dam (10 year avg)
  - 282,000 pass The Dalles Dam (80%) (20% Bonneville Tribs)
  - Of those that pass The Dalles Dam
    - 177,000 go up Snake River passed Ice Harbor Dam (63%)
    - 19,000 go up Columbia passed Priest Rapids Dam (7%)
    - The rest (30%) go to mid-Columbia tribs in eastern OR/WA, including Deschutes & John Day
- Steelhead migrate during warmest part of year
- Migration time from BON to MCN depends of temperature
  - 2-4+ weeks (Keefer et. al. 2004)
- ESA listings include: Middle Columbia, Upper Columbia, & Snake River Steelhead
- A-run (June 1- Aug 25); B-run (Aug 26-Oct) pass Bonneville

Source - FPC 2014 Annual Report

Summer Steelhead – Extensive Use of CWR

- <19C; 10% CWR use; 3-5 days to travel from Bonneville Dam to The Dalles Dam
- 19-21C; 50% CWR use; 5-10 day travel time
- >21C; 71% CWR use; 5-30 day travel time (20+ day average)



Source - Keefer et. al. 2009

Eight Primary CWR Areas studied in Columbia River from Bonneville Dam to McNary Dam

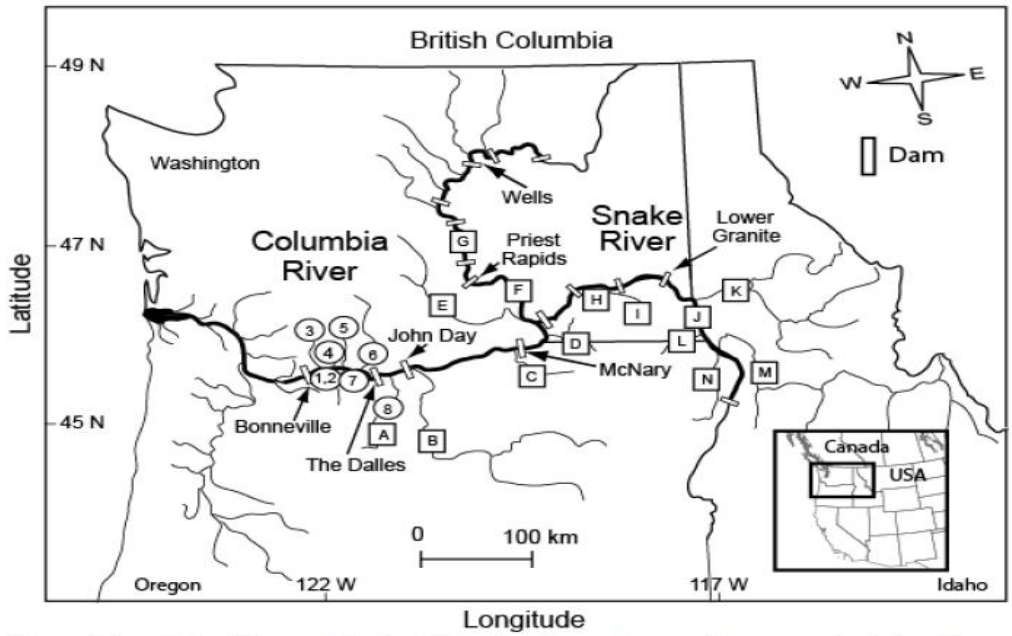


Figure 3. Map of the Columbia and Snake River basins, where radio-tagged adult salmon and steelhead were monitored at dams, in reservoirs, and while using cool water tributaries during migration through the lower Columbia River. Thermoregulatory behaviors were monitored at eight sites: (1) Herman Cr., (2) Eagle Cr., (3) Wind R., (4) Little White Salmon R., (5) White Salmon R., (6) Klickitat R., (7) Hood R., and (8) Deschutes R. Sites A-N were tributary populations used in the steelhead study described in Keefer et al. (2009).

Source - Keefer et. al. 2011

Steelhead Migration Rate and Duration of CWR Use

- Very low migration rate during peak August temperatures
- 1-2+ weeks within CWR area
- Often exit CWR into main stem and quickly return

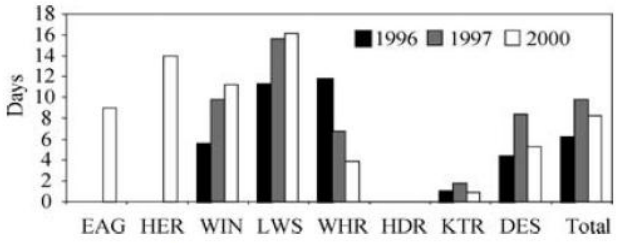


FIGURE 5.—Median residence times of radio-tagged adult steelhead in coolwater tributaries of Bonneville and the Dalles reservoirs on the Columbia River during 1996, 1997, and 2000. The tributaries are Eagle Creek [EAG], Herman Creek [HER], the Wind River [WIN], Little White Salmon River [LWS], White Salmon River [WHR], Hood River [HDR], Klickitat River [KTR], and Deschutes River [DES]). Information for Eagle and Herman creeks was only available during 2000 and is based on daily mobile tracking.

Source - High et. al. 2006

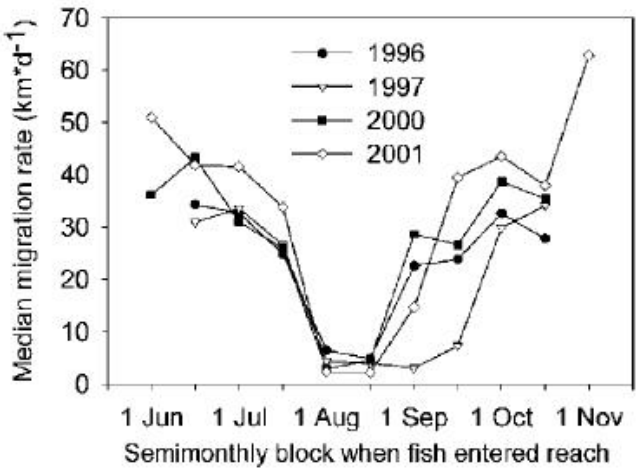


FIGURE 10.—Semimonthly median migration rates for steelhead passing through Bonneville reservoir (Columbia River basin), based on the semimonthly block when fish entered this reach, 1996–2001.

Source - Keefer et. al. 2004

Steelhead holding in CWR Tributaries between Bonneville Dam and John Day Dam

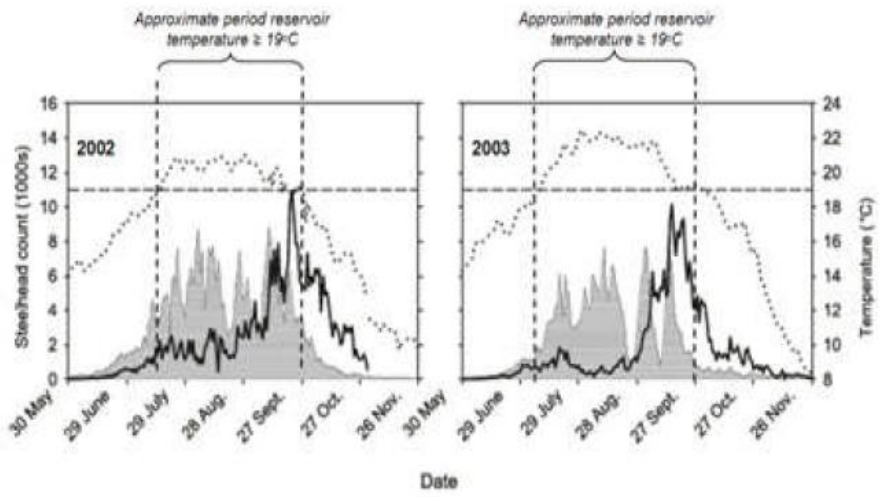


Figure 4. Number of steelhead counted at Bonneville Dam (shaded area) and at John Day (solid black line) for 2002-2003. The vertical dashed lines bound the time periods when an increased use of thermal refuges is observed. The horizontal dashed line at 66.2 °F (19 °C) line is a threshold temperature where use of thermal refuges rapidly increases. The dotted lines are the average daily Columbia River water temperature at the Bonneville Dam. *Sources*: Graph modified from Keefer et al 2009, (2002 and 2003 years excerpted); Columbia River temperatures from DART (water quality monitoring site in Bonneville Dam forebay; *www.cbr.washington.edu/dart/river.html*).

Source - Cramer Fish Sciences, 2011

- Approximately 80,000 Steelhead in CWR tributaries in August
- Based on following rough estimate:
- BON July 15 – Aug 31 = Approx. 5,000 Steelhead/day = 225,000
- 225,000 x .76 (10 year avg. % expected to pass JDA) = 171,000
- JDA July 15 – Aug 31 = Approx. 2,000 Steelhead/day = 90,000
- 171,000 – 90,000 = 81,000 of Steelhead using CWR between BON- JDA

Greater CWR use in Bonneville Reservoir versus The Dalles Reservoir

- Greater number of CWR tributaries in BON reservoir vs TDA reservoir
  - Deschutes River only CWR in TDA res.
  - 7 tributaries in BON res.
- Steelhead that pass The Dalles Dam in Aug and Sept may have already used CWR in BON reservoir and are moving up

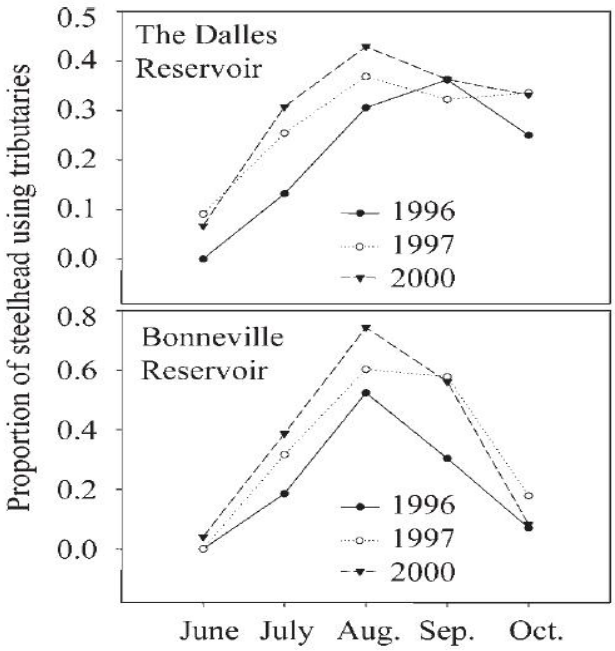


FIGURE 3.—Proportion of radio-tagged adult steelhead that entered Bonneville and the Dalles reservoirs on the Columbia River each month and that used one or more coolwater tributaries in 1996, 1997, and 2000.

Source - High et. al. 2006

Steelhead populations that migrate in heat of the summer use CWR the most

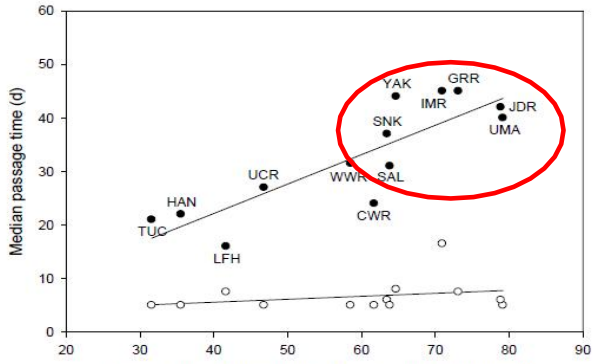


Figure 8. Relationships between median population-specific steelhead passage times from the top of Bonneville Dam to the top of John Day Dam and the percentages of steelhead that were (●) or were not (○) recorded in cool-water tributaries for > 12 h. Labels represent specific upriver populations. From Keefer et al. (2009).

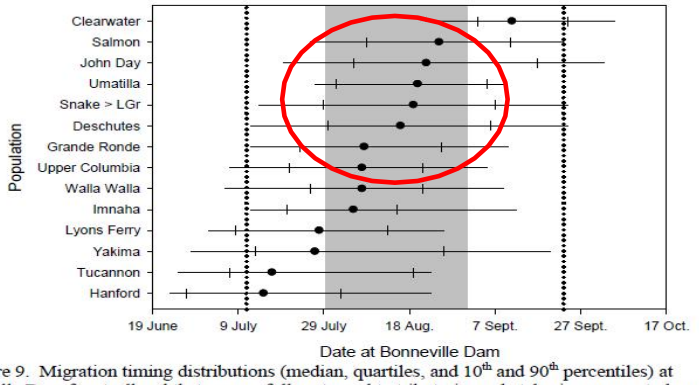


Figure 9. Migration timing distributions (median, quartiles, and 10th and 90th percentiles) at Bonneville Dam for steelhead that successfully returned to tributaries or hatcheries across study years. Vertical dotted lines show mean first and last dates that Columbia River water temperature was 19 °C; the shaded area shows dates with mean temperature ≥21 °C. From Keefer et al. (2009).

Later migrating populations during peak August temperature use CWR the most

- ✓ John Day
- ✓ Umatilla
- ✓ Grande Ronde
- ✓ Snake River
- ✓ Salmon
- ✓ Imnaha

Less CWR use for populations that migrate early

- ✓ Hanford
- ✓ Tucannon
- ✓ Upper Columbia

Source - Keefer et al. 2011

Steelhead population use of specific CWR areas in the Columbia River

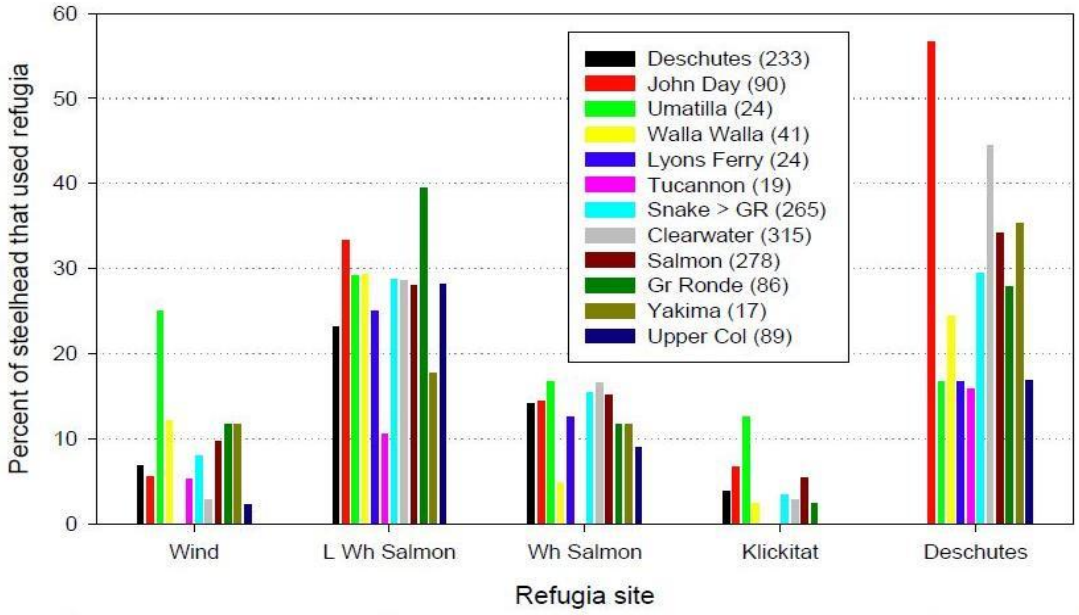


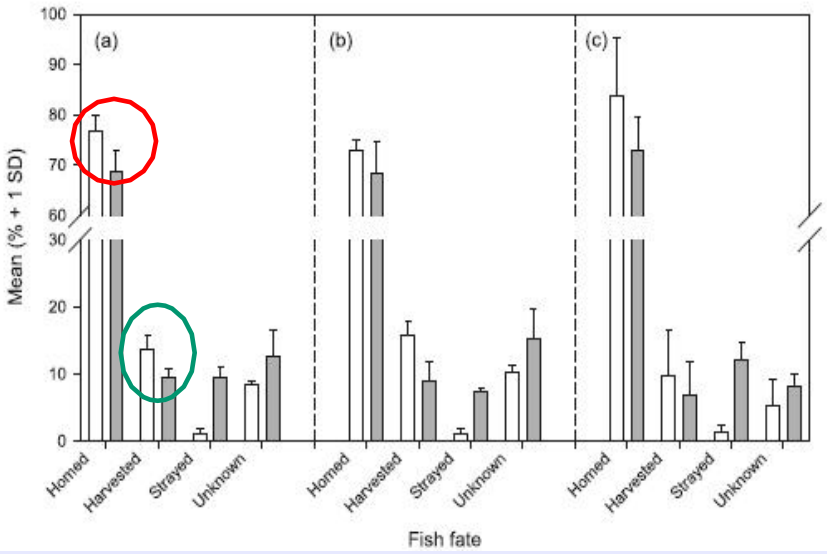
Figure 7. Population-specific use of selected cool-water refugia tributaries in the Bonneville-John Day reach by radio-tagged summer steelhead in 1996-1997 and 2000. Bar colors represent upriver populations, with sample sizes in parentheses. Steelhead additionally used Herman and Eagle creeks, but these small sites were inconsistently monitored in these study years. A small number of steelhead temporarily used the Hood River (not shown).

Source - Keefer et al. 2011

Steelhead beneficial use of CWR appears to be offset by increased harvest in CWR

- Those that used CWR were 8% less likely to survive to natal streams
- 5% less survival for wild and 11% less survival for hatchery
- Higher harvest rate for Steelhead that use CWR

Fig. 7. Mean annual estimates of homing, main stem harvest, straying, and unknown fate for known-origin steelhead (*Oncorhynchus mykiss*) that were (shaded bars) or were not (open bars) recorded using tributary thermal refugia in the lower Columbia River during the 2001–2003 migrations. (*a*) All fish; (*b*) wild fish; (*c*) hatchery fish. The "strayed" category includes permanent strays to nonnatal basins and fish reported harvested inside monitored tributary refugia.



Source - Keefer et. al. 2009

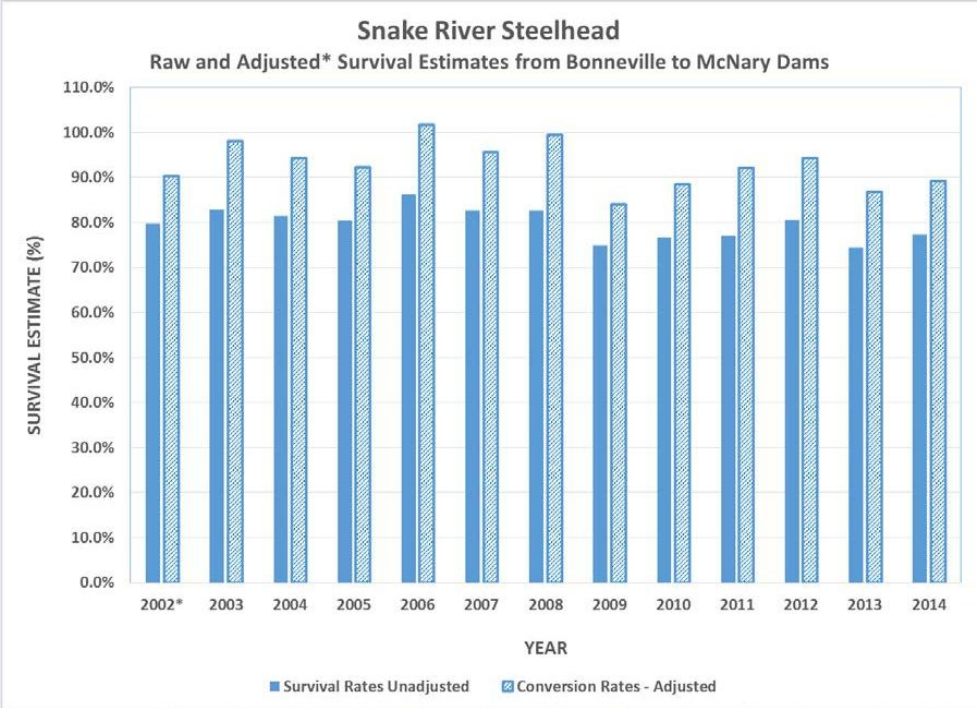
90% Snake River Steelhead Survival from Bonneville to McNary Dam (excluding harvest and straying loss)

2010-2014 average

- 10% unaccounted loss in this reach of Columbia River
- 10% harvest loss in Zone 6
- 4.7% est. stray loss

BiOp Target (2002-2007)

- 95% adjusted survival (5% unaccounted loss)



Source - NOAA Fisheries Data, 2016

93% Upper Columbia Steelhead Survival from Bon to MCN (excluding harvest and straying loss)

<u>2008-2012 average</u>

- 7% unaccounted loss in this reach of Columbia River

<u>BiOp Target</u> (2002-2007)

- 85% adjusted survival (15% unaccounted loss)
- 8% Zone 6 harvest
- 5% est. straying loss

UCR Steelhead - Conversion Rate Estimates from Bonneville to McNary Dams

Based on PIT tag detections of known origin adults (excluding one-ocean jacks) that migrated inriver or were transported as juveniles
Adjusted conversion rates are calculated as (# at MCN or LGR / # at BON) / ([1-Harvest Rate]*[1-Stray Rate])

	Adults (hatchery) that migrated inriver as juveniles					
	PIT Tag Detections at BON and upstream redetections		Unadjusted Conversion Rate	Adjustment Estimates		Adjusted Conversion Rates
Year	Number at BON	Redet. @ MCN*	BON to MCN (%)	Zone 6 Harvest Rate**	Stray Rate	BON to MCN (%)
2002*	294	232	78.9%	7.3%	3.8%	88.5%
2003	44	34	77.3%	10.1%	5.3%	90.7%
2004	3448	2468	71.6%	8.0%	4.7%	81.6%
2005	6123	4200	68.6%	7.3%	4.7%	77.6%
2006	6790	4944	72.8%	9.2%	4.7%	84.1%
2007	1167	856	73.4%	8.8%	4.7%	84.4%
Mean			73.8%	8.4%	4.6%	84.5%
						95.9% equals .986^3

The vast majority of tagged fish in this analysis are of hatchery origin.
The Zone 6 harvest estimate for 2007 was estimated as the average of the 2004-2006 estimates.

NOTE: Harvest estimate was assumed to be equal to that of A&B-run hatchery SR steelhead.

Species	Years	BON to MCN	MCN to LGR	BON to LGR
UCR Steelhead	2008 BiOp Standard (2002–2006 data)	**84.5%**		
	2008–2011 Average	**93.2%**		
	Difference	**+8.7%**		

Sources - NOAA Fisheries 2008 and 2014

Steelhead – Summary

- Extensive use of CWR in Columbia River when temperatures exceed 19C, which is about for 2 months during the peak of the run
- Recent adjusted survival for Snake River Steelhead in the Columbia River is 90% (10% unaccounted loss), which is lower than the 95% BiOp target
- Recent adjusted survival for Upper Columbia Steelhead in the Lower Columbia River is 93% (7% unaccounted loss), which is better than the 85% BiOp target
- Snake River Steelhead migrate in warmer temperatures and use CWR more than Upper Columbia Steelhead
- Those steelhead that use CWR have less survival to natal streams likely due to higher harvest rates/fishing pressure in CWR

Chinook Salmon - Overview

- Summer Chinook
  - Pass Bonneville Dam from June 1 – July 31 (by definition)
  - 80% pass from June 5 – July 15; declining numbers thru July
  - 85,000 Adults 10-year average
  - 7 day migration time from BON to MCN (Keefer et. al. 2004)
  - Majority (~80) go to upper-Columbia (e.g., Wenatchee, Methow)
    - Not ESA listed; hatchery and wild; 20-30% harvest rate in Zone 6 in recent years
  - A portion (~20%) are part of ESA listed SR Spring/Summer Chinook
    - Primarily from South Fork Salmon, Imnaha, and Pahsimeroi populations
- Fall Chinook
  - Pass Bonneville Dam from Aug 1 – October (by definition)
  - 80% pass from late Aug – late Sept
  - 425,000 Adults 10-year average (900K in 2013/2014)
    - Roughly 50% pass McNary Dam
      - Hanford Reach, upper Columbia River and Snake River populations
    - Roughly 50% harvested or spawn in tributaries below McNary Dam
  - 8-9 day typical migration time from BON to MCN (Keefer et. al. 2004)
  - Only Snake River Fall Chinook ESA listed

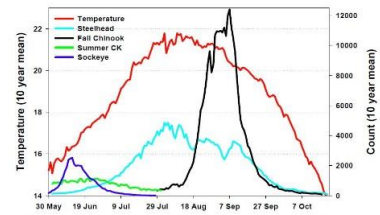


Figure 2. Ten-year (1996-2005) mean lower Columbia River water temperature (°C) and mean run size and timing of adult summer Chinook salmon, fall Chinook salmon, sockeye salmon, and summer steelhead at Bonneville Dam. Thermal refugia use by many adult populations has been associated with water temperatures greater than 19-20 °C.

Sources: FPC 2014 Annual Report; WDFW/ODFW 2016 Joint Staff Report; Crozier, 2016

Chinook use of CWR

- CWR use associated with 21C temperature
- 20-40% use CWR with 21-22C
  - Migration rate cut in half
- 20% of Fall Chinook run used CWR tributaries
  - 9% of Fall Chinook used CWR greater than 12 hours
- 15% of Summer Chinook run use CWR
- CWR tributaries used
  - Little White Salmon
  - White Salmon
  - Deschutes
  - Klickitat
  - Wind
- Plume use as well (not counted as CWR use – so above statistics don't account for this)

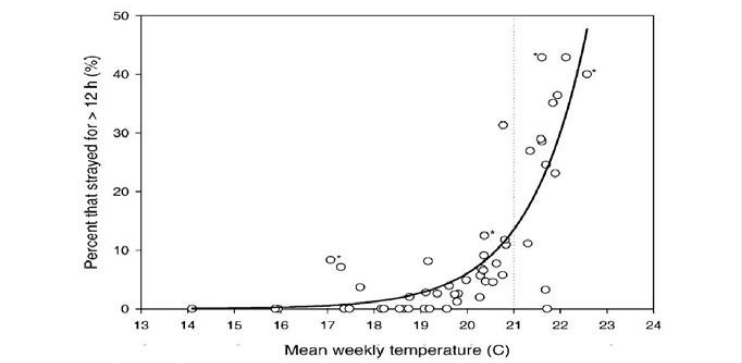


FIGURE 6.—Relationship between the percent of fall Chinook salmon that used (>12 h) coolwater tributaries and mean weekly water temperatures at Bonneville Dam. Circles represent 52 weekly bins (mean = 41 fish/bin; range = 4–122 fish/bin). The curve is the exponential regression line that best fits the data ($r^2 = 0.80$; $P < 0.0001$; percent = $6.558^{-7} e^{0.802 \times \text{temperature}}$). Asterisks indicate data points with fewer than 10 fish.

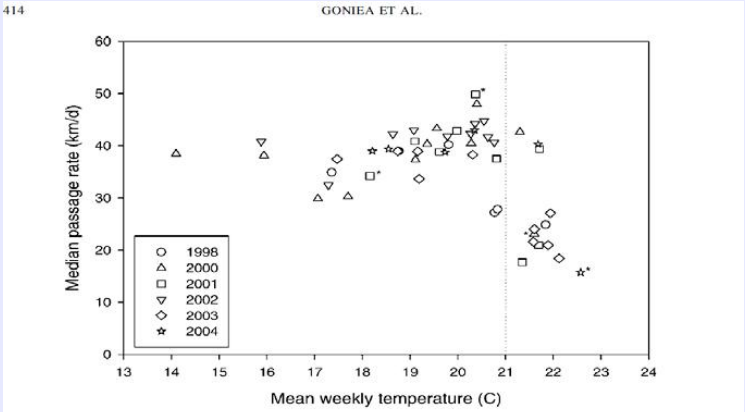


FIGURE 5.—Relationship between median fall Chinook salmon migration rates (Bonneville Dam to John Day Dam) and mean weekly water temperatures at Bonneville Dam. Symbols represent 52 weekly bins (mean = 41 fish/bin; range = 4–122 fish/bin). Asterisks indicate data points with fewer than 10 fish.

Sources - Goniea et. al. 2006; Keefer et. al., 2011

Fall Chinook runs with highest percentage of 21C exposure and CWR use

- Greatest % exposure for Fall Chinook runs above Priest Rapids and Deschutes (not ESA listed)
- Is this still representative? Especially for SR?

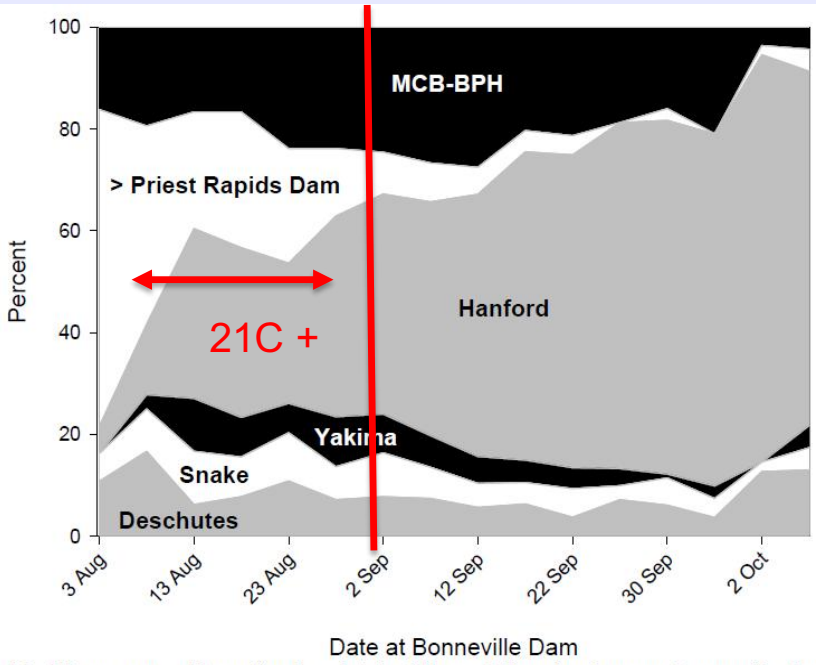


Figure 12. Mean composition of upriver bright fall-run Chinook salmon at Bonneville Dam using 5-day intervals based on release dates of radio-tagged fish, 1998 and 2000-2004. MCB-BPH = mid-Columbia River bright–Bonneville Pool hatchery stock. From Jepson et al. (2010).

Source - Keefer et. al. 2011

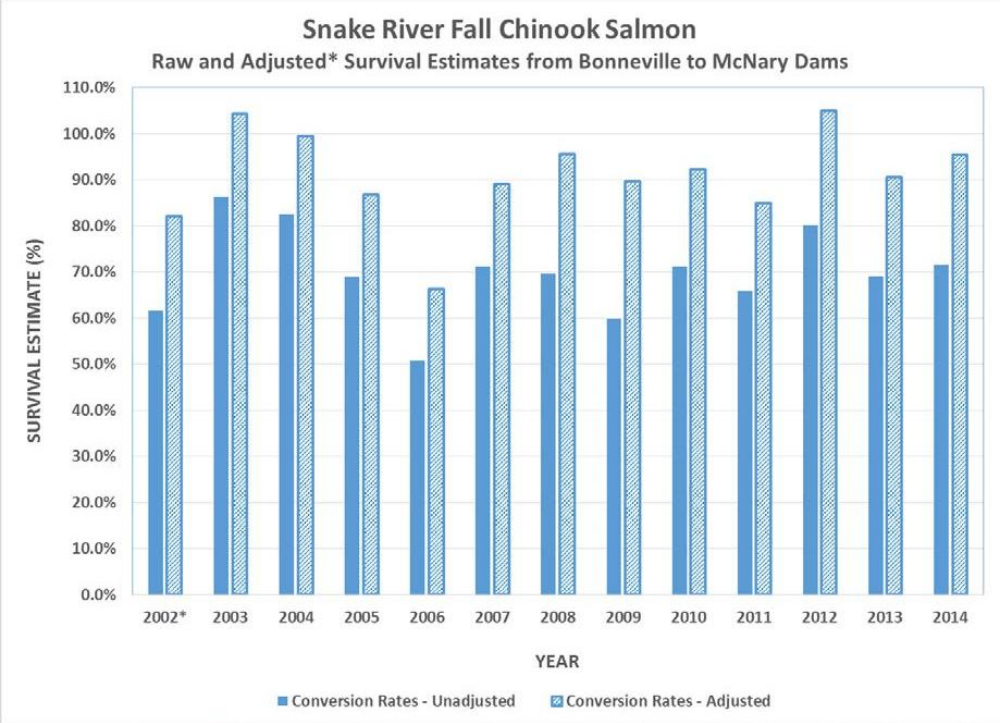
92% Snake River Fall Chinook Survival from Bonneville Dam to McNary Dam (excluding harvest and straying loss)

2010-2014 average

- 8% unaccounted loss in this reach of Columbia River
- 23% harvest loss in Zone 6
- 3.3% est. stray loss

BiOp Target (2002-2007)

- 88% adjusted survival (12% unaccounted loss)



Source - NOAA Fisheries Data, 2016

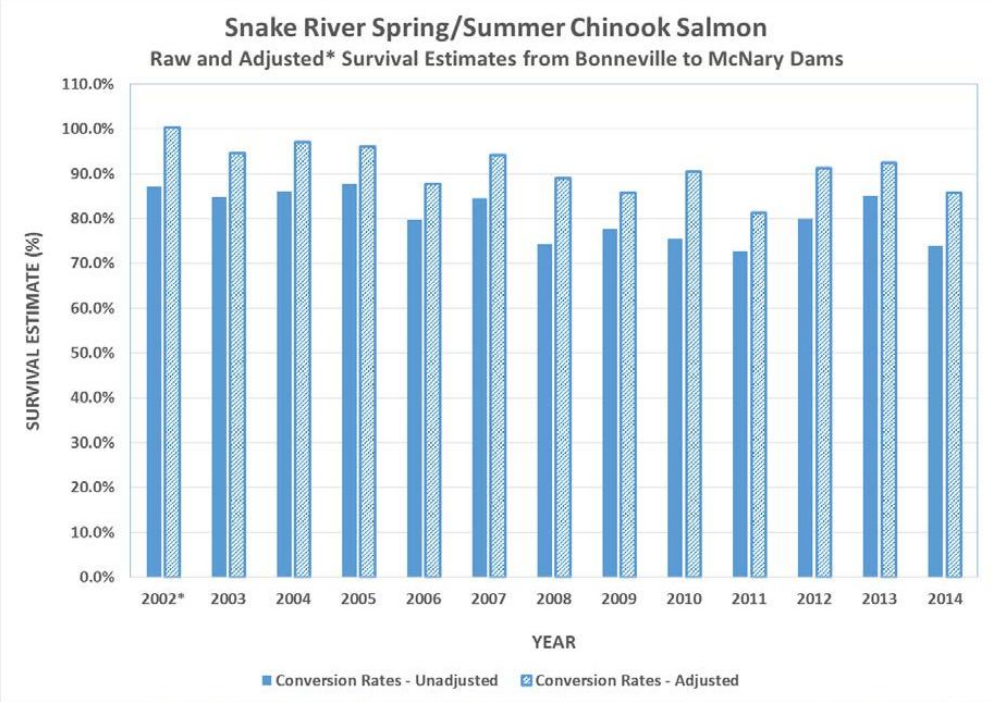
88% Snake River Spring/Summer Chinook Survival from BON to MCN (excluding harvest loss and straying)

2010-2014 average

- 12% unaccounted loss in this reach of Columbia River
- 10% harvest loss in Zone 6
- 2% est. stray loss

BiOp Target (2002-2007)

- 95% adjusted survival (5% unaccounted loss)



Source - NOAA Fisheries Data, 2016

Snake River Summer Chinook Survival Comparisons

- Snake River Summer Chinook decreased survival 2013-2015 in BON-MCN reach
  - Associated with elevated temperatures
  - More mortality in Columbia River than Snake River
- Transported juvenile fish less survival than non-transported

Source: FPC Oct 2015 Memo

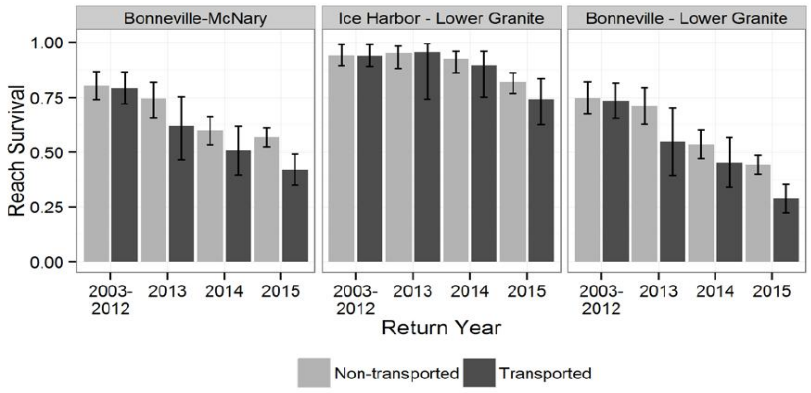


Figure 9. Bar plots of hatchery Snake River summer Chinook adult reach survival with 95% confidence intervals by return year, river reach, and juvenile migration history.

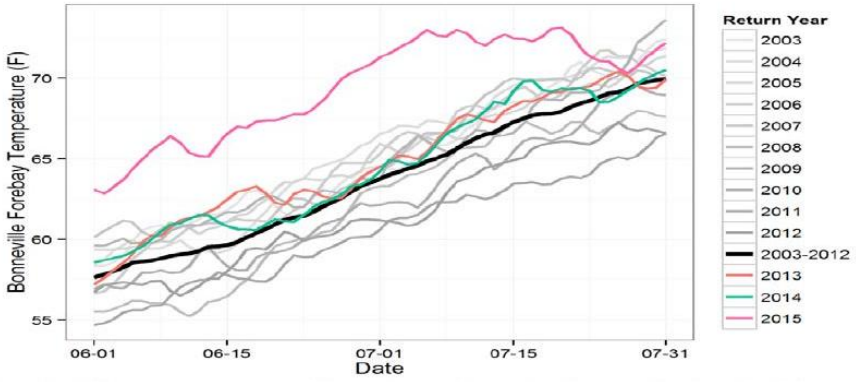


Figure 1. Daily average temperature (°F) in the Bonneville Dam forebay from June 1 to July 31 by return year.

Summer Chinook Survival Temperature Relationship

- Decreased survival associated with increased temperature at time of Bonneville Dam passage

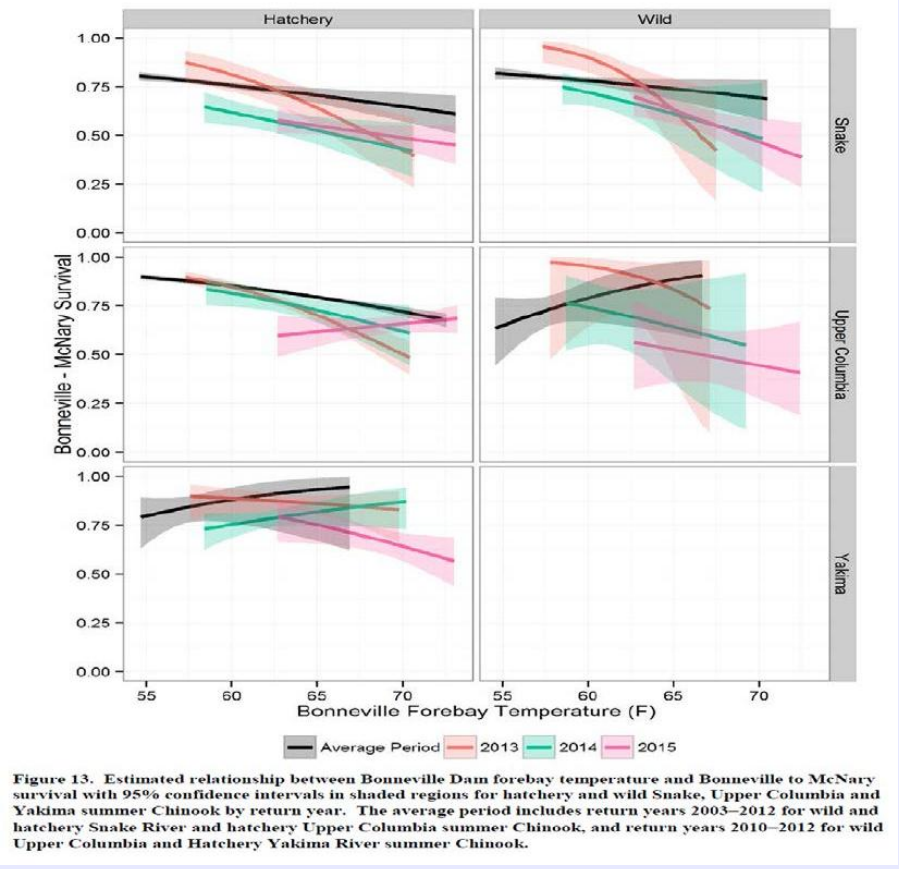


Figure 13. Estimated relationship between Bonneville Dam forebay temperature and Bonneville to McNary survival with 95% confidence intervals in shaded regions for hatchery and wild Snake, Upper Columbia and Yakima summer Chinook by return year. The average period includes return years 2003–2012 for wild and hatchery Snake River and hatchery Upper Columbia summer Chinook, and return years 2010–2012 for wild Upper Columbia and Hatchery Yakima River summer Chinook.

Source:
FPC Jan 2016 memo

Chinook - Summary

- Significant use of CWR by Fall Chinook when temperatures exceed 21C, which occurs for the first 10-15% of the run in August
- Significant use of CWR by Summer Chinook in the latter 10-15% of run in July
- Recent SR Fall Chinook adjusted survival though Columbia River (92%) slightly better than BiOp target (88%)
- SR Spring/Summer Chinook adjusted survival through Columbia River (88%) has dropped relative to BiOp target (95%) and decreased survival correlated with elevated temperatures

Sockeye - Overview

- Two major populations
  - Upper Columbia River (spawn in Okanogan River/Lake)
    - Not listed under ESA
    - 167,000 10-year average over Priest Rapids Dam
    - 608,000 record run in 2014
  - Snake River (spawn in Redfish Lake)
    - ESA Listed - Endangered
    - 505 10-year average over Ice Harbor Dam
    - 2,400 record run in 2014
- Pass Bonneville Dam between Mid-June and Mid-July
  - 90% of run passes in 26 days (FPC 2014 Annual Report)
  - UCR pass 3-5 days earlier than SR (FPC Oct. 2015 Memo)
  - 5 day typical migration time from BON to MCN
- 21C (70F) migration temperature associated with high mortality
  - Keefer et. al. 2008

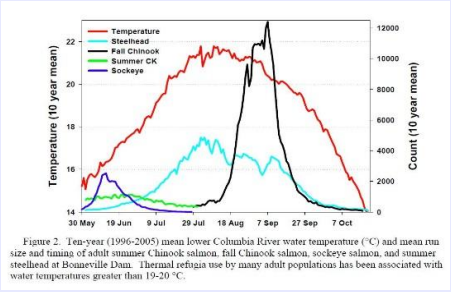


Figure 2. Ten-year (1996-2005) mean lower Columbia River water temperature (°C) and mean run size and timing of adult summer Chinook salmon, fall Chinook salmon, sockeye salmon, and summer steelhead at Bonneville Dam. Thermal refugia use by many adult populations has been associated with water temperatures greater than 19-20 °C.

Sockeye – Columbia River Survival

- Recent Bonneville to McNary Dam survival typically around 50-80%
  - Mostly unaccounted mortality
- Significant decreased survival in 2015

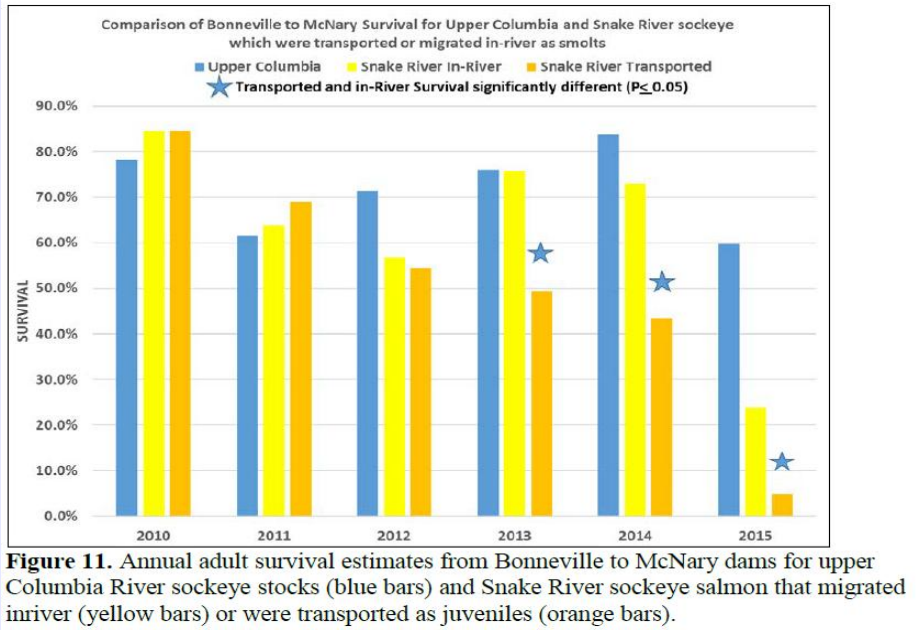
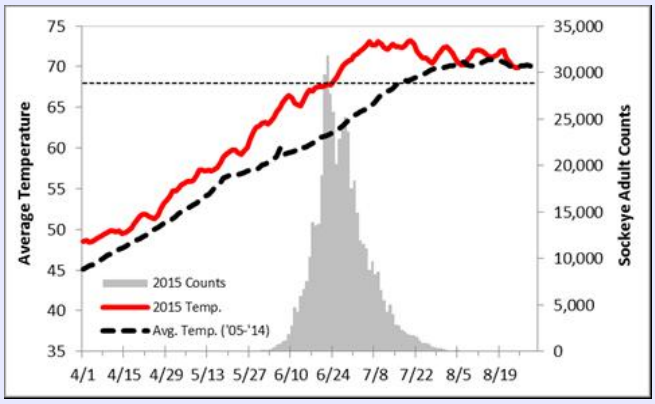


Figure 11. Annual adult survival estimates from Bonneville to McNary dams for upper Columbia River sockeye stocks (blue bars) and Snake River sockeye salmon that migrated inriver (yellow bars) or were transported as juveniles (orange bars).

Source: NOAA draft Sockeye Report 2016



Source: FPC Oct 2015 memo

Sockeye – Columbia River Survival Temperature Relationship

- Bonneville to McNary Survival drop off at 20C and above (2015)
- 2013 & 2014 low survival in later part of run (associated with higher temps)

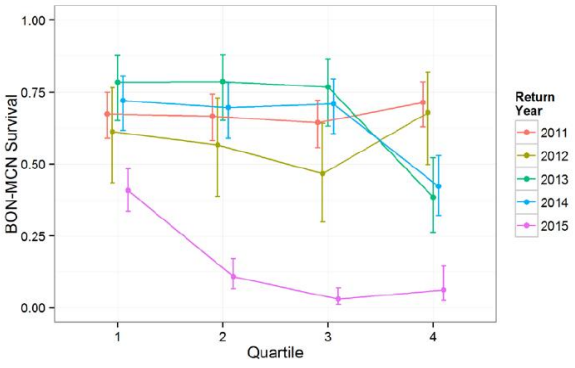


Figure 7. Survival from Bonneville to McNary Dam by run grouping determined by quartiles (i.e., first 25% of the run (1), 26%–50% of the run (2), etc.).

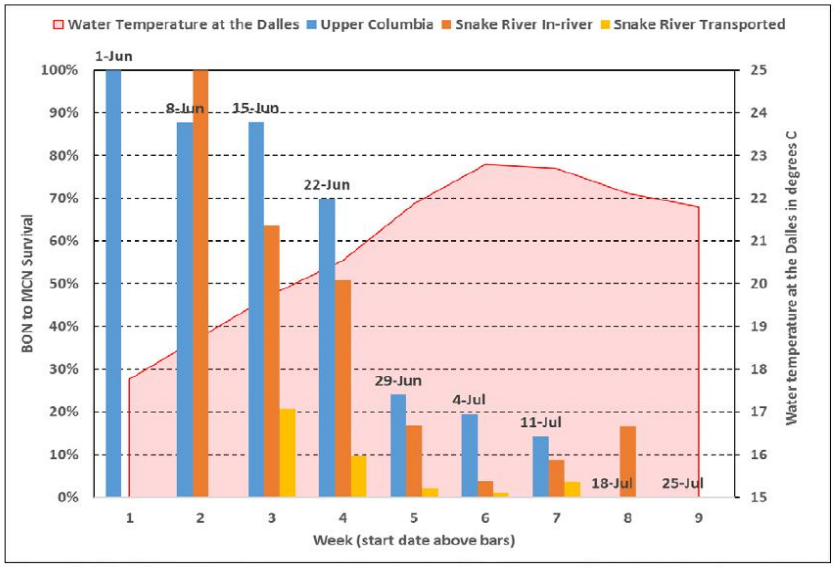


Figure 9. Weekly adult sockeye survival estimates from Bonneville to McNary dam in 2015 for Upper Columbia River sockeye salmon (blue bars), Snake River sockeye salmon that migrated inriver as juveniles (orange bars), and Snake River sockeye that were transported as juveniles (yellow-orange bars) with water temperatures (red line) at The Dalles Dam. Source: PITAGIS data and Columbia River DART.

Source: NOAA draft Sockeye Report 2016

Source: FPC Oct 2015 Memo

Sockeye – Columbia River Survival Temperature Relationship

- Sockeye arriving at Bonneville Dam when Temps are 64F (18C) and higher have decrease survival
  - 68F (20C) associated with 25% survival
- Snake River population most susceptible
  - Later run-timing
  - Transported juveniles

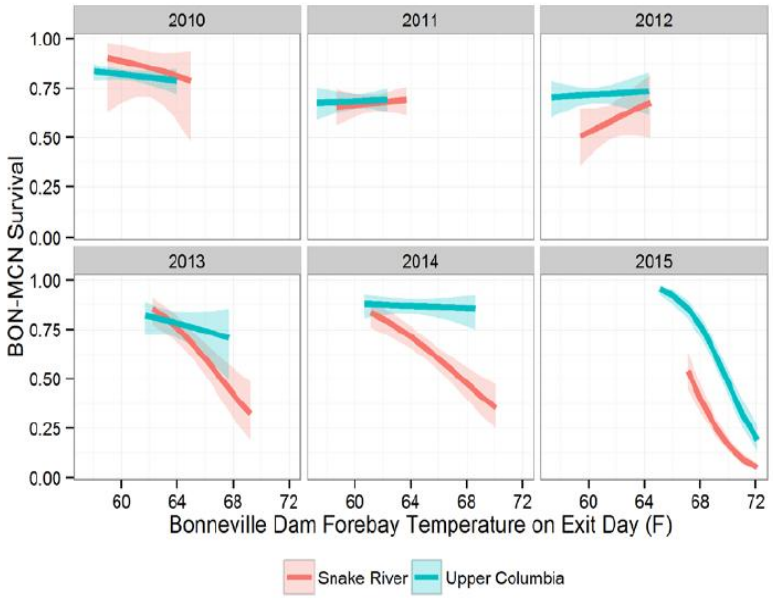


Figure 15. Estimated relationship between Bonneville Dam forebay temperature and Bonneville to McNary Dam survival by return year for Snake and Upper Columbia River adult sockeye. The shaded portion of the curves indicates 95% confidence intervals. All available data are used for the fitted relationship, but only the 2.5th to the 97.5th percentiles of observed temperatures in each return year are shown.

Source: FPC Oct 2015 Memo

Snake River Sockeye Survival Comparisons

- Bonneville to McNary survival lower than McNary to Lower Granite survival
- Transported juveniles lower survival than non-transported

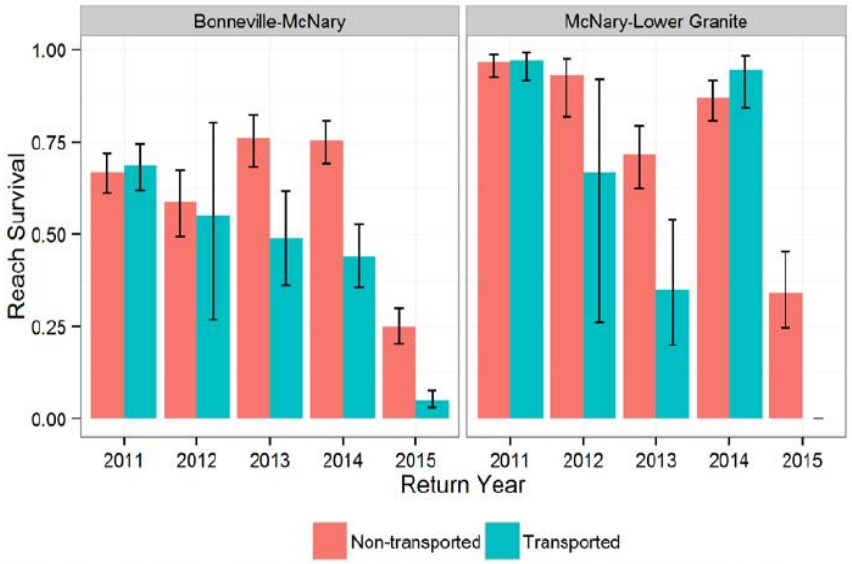


Figure 8. Snake River sockeye adult survival (95% confidence interval), from Bonneville to McNary, and McNary to Lower Granite Dam by return year and migration history.

Source: FPC Oct 2015 Memo

Sockeye migration timing shifting earlier

- Increasing Columbia/Snake River summer temperatures likely a primary factor
- Future June/July temperature increase from climate change (e.g., 2015) a significant concern
- Mitigation options?
- Can populations adapt?

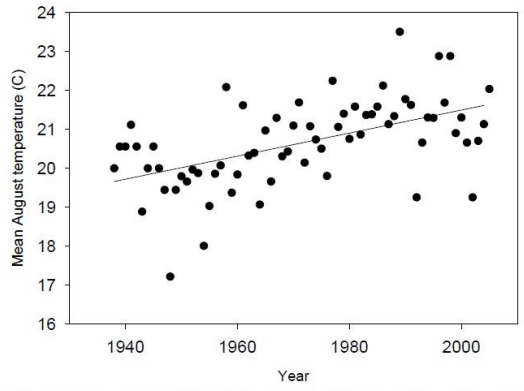


Figure 1. Mean August water temperature (°C) at Bonneville Dam, 1938-2005. Source: Columbia River DART.

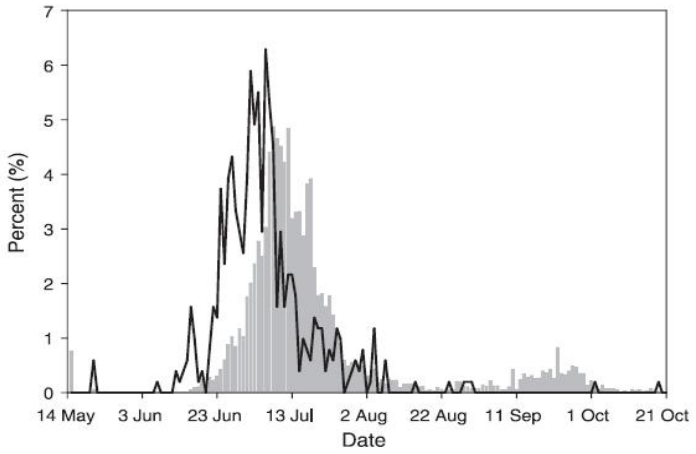


Fig. 5. Frequency distributions of sockeye salmon counted passing Ice Harbor Dam on the lower Snake River from 1962–1998 (grey bars, $N = 10{,}676$) and from 1999–2006 (black line, $N = 517$) showing a shift towards earlier run timing.

Source - Keefer et. al. 2011

Sockeye – Summary

- Limited studies of Sockeye CWR use in Columbia River
- Sockeye very susceptible to elevated temperatures, with 20-21C associated with high levels of mortality
- Sockeye survival through the Columbia River highly correlated to temperatures
- 2013-2015 higher than average late June/July temperatures associated with high mortality rates in Columbia River

Wrap-Up and Closing Thoughts

- Round robin summary thoughts from workshop participants
- Next Steps
  - Notes from workshop
  - Follow-up with participants
  - EPA develops draft Chapter 2 and solicits comment
  - EPA develops sufficiency methodology, HexSim Model, and draft Chapter 3

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